THE UNIVERSITY OF CHICAGO
THE ENRICO FERMI INSTITUTE
933 EAST 56TH STREET
CHICAGO ILLINOIS 60637

Laboratory for Astrophysics
and Space Research
TEL. NO. (312) 702-7672
FAX NO. (312) 702-6645

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ASTROPHYSICAL STUDIES WITH IMP DATA
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C. Lopate, Principal Investigator
J. A. Simpson, Co-Investigator

ANNUAL STATUS REPORT
FOR THE PERIOD 1 OCTOBER 1994 - 30 SEPTEMBER 1995

A. SCIENTIFIC WORK.

The aims of the work done under NASA Grant NAG 5-706 are as specified in the original proposal. IMP-8 data has been used at the University of Chicago, during the period 1 October 1994 through 30 September 1995, to advance research in the following areas:

1. Studies of the Galactic Cosmic Ray Propagation in the Heliosphere During the 22-year Solar Magnetic Cycle.

Data from the University of Chicago experiments on IMP-8, Pioneer-10 and -11, and the neutron monitors at Climax and Haleakala have been updated to 1995. These data are used along with our 2-dimensional solar modulation code in order to better understand the propagation of charged particles through the heliosphere.

The conditions in the heliosphere are once again approaching solar minimum levels, now for the third time since IMP 8 was launched. The present 1 AU data indicate that the cosmic ray flux for this solar minimum more closely resembles the time history and intensity levels seen during the 1977 solar minimum than that seen during the 1987 solar minimum. These observations support the drift-dominated solar modulation models which predict alternating profiles each 11 years of the full 22-year solar modulation cycle. The next ~3 years of data will be crucial to determining the level to which gradient and curvature drifts -- as opposed to merged interaction regions -- effect cosmic ray propagation in the heliosphere.

2. Studies of Cosmic Ray Fluxes at High Levels of Solar Modulation.

The final reports of the studies of CRRES and IMP-8 elemental cosmic ray fluxes were completed in late 1994. With the data from CRRES and IMP-8 we were able to derive an empirical, self-consistent model for the propagation of cosmic rays through the heliosphere during high levels of solar activity. We compared the model predictions to data collected during the 1990-91 period, when the second highest level of solar activity was seen since cosmic ray monitoring began. The model accurately fit both the spectral shape and flux intensity of all elements from helium through nickel over our measurement range of ~10-550 MeV/nuc. We hope to use this model during the next solar maximum in ~2001.

3. Studies of the Anomalous Component of Cosmic Ray Hydrogen in the Heliosphere.

We have used cosmic ray measurements of the isotopic ratio of deuterium to protons ($^2H/^1H$) from our experiments on Pioneer-10 and IMP-8 to show conclusively that there is an anomalous component of hydrogen in the heliosphere. This confirms the first report from CalTech and a later report from our group at the University of Chicago, both of which were only tentative identifications of anomalous hydrogen. The analysis method we used relied on the full mission's data, ~22 years. We showed that ~60% of the hydrogen measured in the outer heliosphere and ~10% of the hydrogen measured at 1 AU during the 1987 solar minimum and at the present 1995 period is from the anomalous component. The analysis also indicated that the proton superflux, originally reported by the University of Chicago during the 1977 solar minimum, was actually the appearance of anomalous hydrogen at Earth.

Our analysis will be continued in the future in order to answer the remaining question of why so little anomalous hydrogen is seen as opposed to other anomalous species. We hope to be able to determine whether the low level of anomalous hydrogen is due to the filtering of neutral hydrogen at the heliospheric boundary or if it is due to inefficient pick-up and/or acceleration of hydrogen compared to other anomalous species.

4. 3-Dimensional Studies of the Heliosphere using Cosmic Ray Rates from IMP-8 and Ulysses through 1995.

From September 1994 through June 1995 the Ulysses spacecraft traveled from the south polar region to the north polar region of the Sun. The IMP-8 data taken during this period were crucial to a proper interpretation of the Ulysses results.

The normalized Ulysses/IMP-8 rates showed that the latitudinal gradients of all cosmic ray and anomalous species were small, $\leq$ 2%/degree, in both the southern and northern hemispheres. Data taken during the fast equatorial pass in February 1995 showed that the cosmic ray fluxes measured on Ulysses, when corrected for intensity changes measured on IMP-8, reached a minimum of intensity at a heliospheric latitude of ~10°S. There was an increase in the cosmic ray intensity in the north polar region when compared to the south polar region, above the general increase measured by IMP-8 over this same time period. This increase was attributed completely to the offset of the helio-magnetic equator to ~10°S solar latitude as determined during the fast equatorial pass.

We will continue our Ulysses/IMP-8 investigations through the extended Ulysses mission. The next Ulysses solar pass will occur in ~2001, during solar maximum conditions. The comparison between the just completed solar pass and the expected pass in ~2001 will give us crucial information about the dynamics of the solar environment. We hope to understand better the effects of different solar magnetic field and plasma configurations, as seen during these extremely different solar activity levels, on cosmic ray propagation.

B. RESEARCH OBJECTIVES FOR THE PERIOD 1 OCTOBER 1995 - 30 SEPTEMBER 1996.

We plan to continue our investigation on the general field of solar modulation with special emphasis on heliospheric propagation, the origin of the anomalous components and dependence on the charge sign of the modulated particles.

With the new data from the recovery in the galactic cosmic ray intensity in 1995-1996 we will have essentially continuous data coverage both from space and from neutron monitors comprehending almost three complete solar cycles (1965-1996 data). We plan to continue with these data our study of the changing conditions in the propagation of energetic particles in the heliosphere. Our emphasis during the next year will be on the similarities of the 1997 solar minimum to the 1977 solar minimum, and on the differences with the 1987 solar minimum.

The study of the nature and source of the anomalous components is a field which may lead to fruitful insights of the nature of the solar modulation and the size of the heliosphere. We will continue our study of the time, the space dependence and the charge of the hydrogen, helium and oxygen anomalous components as revealed by the data from our experiments on IMP-8 and Pioneers-10 and 11. We will check the consistency of these data with models of origin of the anomalous components and with models of the shape, extension and boundary conditions of the heliosphere. This study will also reach important constrains on the role of particle drifts on solar modulation.

We will continue the analysis of Ulysses and IMP-8 data with the intent to discover more about the 3-dimensional structure of the heliosphere. We hope to be able to confirm the offset of the helio-magnetic equator and better quantify the differences in cosmic ray propagation through the northern and southern hemispheres of the heliosphere.

C. IMP-8 DATA PROCESSING

• Submitted Helium fluxes to NSSDC for NOAA on: April 25, 1995. This shipment extended our coverage at NSSDC through December 1993.

• Annual submission of IMP-8 data to NSSDC on April 25, 1995 consisted of:

1. 4 magnetic tapes containing Rate data for the time period October 8, 1991 through June 8, 1994.

2. 30 magnetic tapes containing JOST data recorded at 6250 BPI in a compressed format for Production Run Numbers 1622 through 1861 (October 16, 1991 through June 16, 1994).

This extended our coverage at NSSDC through June 8, 1994.

• As of this shipment of data we plan to keep our IMP-8 archival submissions at 1 year behind the present.

Journal and Refereed Papers

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Abstracts and Conference Proceedings

Lopate, C., "The Deuterium/Proton Ration as a Measure of Anomalous Hydrogen", Proc. 24th Int'l. Cosmic Ray Conf. (Rome), *Proc. 24nd Int'l. Cosmic Ray Conf. (Rome), V. 4*, 812, 1995.

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Lopate, C., R. B. McKibben, J. A. Simpson and M. Zhang, "Proton Superfluxes and the Proton and Helium Anomalous Components: Investigations in Three Dimensions of the Heliosphere", *28th ESLAB Symposium on the High Latitude Heliosphere, (Friedrichshafen, Germany)*, 19-21 April, 1994.

Connell, J. J., C. Lopate, R. B. McKibben, J. A. Simpson and M. Zhang, "Ulysses and IMP 8 Observations of Variations in Proton and Helium Intensities and Spectra with Increasing Solar Latitude during the 1992-93 Approach to Solar Minimum", *EOS Trans. AGU, vol. 74 no. 43*, supplement p. 481, 1994.